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A Comparative Field Study of Calcium Magnesium Acetate and Rock Salt

During the Winters of 1986-87 and 1987-88

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Abstract:	The field study was undertaken during the winters of 1986-87 and 1987-88 to compare the performance of calcium magnesium acetate (CMA) and rock salt as deicing chemicals. The study included a determination of the deicing effectiveness, and the handling and storage characteristics of the two chemicals. The CMA was applied to a section of freeway and the adjacent sections of service roads near Beamsville, Ontario. The adjoining sections of freeway and service roads served as control sections. The CMA and salt were applied at specified rates and the frequency was dictated by the road conditions. The condition of the test sections was recorded by independent monitors at one-hour intervals during all winter storms. A further section of service road was used to investigate different applicaton rates of CMA. The CMA was found to be comparable to salt in achieving bare pavement though more CMA was used than salt. CMA was found to be relatively more effective in longer storms than salt, and there was a residual effect from one storm to the next. The storage and handling characteristics of CMA were also similar to those of salt. Modifications to equipment were not required and spreading procedures were changed only slightly. The corrosion of the CMA spreader unit was substantially less than that of the salt spreader unit.
Comments:	This report, which updates and supercedes report ME-87-16, contains the text of a paper prepared for the 1988 Annual Meeting of Roads and Transportation Association of Canada and data on deicer applications.
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1. INTRODUCTION

The Ministry of Transportation is required to maintain its roads as free from the hazards of ice and snow as possible, but is also committed to reducing the negative impacts of the use of rock salt. These efforts have resulted in the more efficient use of rock salt through more judicious application, improved equipment controls, and better storage facilities. Simultaneousiy, there has been a continuing search for an effective, non-polluting and non-corrosive alternative to rock salt. A possible alternative is calcium magnesium acetate (CMA) which is a mixture of calcium acetate and magnesium acetate manufactured from dolomitic limestone and acetic acid. CMA was identified in research studies in the late 1970's (1) and has been the subject of several laboratory and field investigations to determine its effectiveness as a deicer and its effect on the environment (2-7).

In order to assess the potential impact of CMA on the Ministry's winter maintenance operations, a field trial was carried out during the winter of 1986-7. The study was continued, with minor modifications during the winter of 1987-8.

2. SCOPE OF THE STUDY

The main objective of the study was to investigate the effectiveness of CMA as a deicer. Additional areas of investigation included storage properties, handling and spreading characteristics, and corrosion of the spreading equipment. With the cooperation of the Ontario Ministry of the Environment, the study was enlarged to examine the movement of

traffic-generated aerosols, and the effect of CMA on fruit trees and soil composition. This paper is concerned only with the operational characteristics of CMA.

During the winter of 1986-7, the test site was a 2.4 km section of the Queen Elizabeth Way (QEW) near Beamsville and included both the freeway and adjacent service roads. The test site is located in an area of soft fruit porduction. The sections of freeway and service roads immediately to the east, which were similar to the CMA test site in all aspects of concern, were maintained using salt applied in accordance with standard Ministry procedures and served as the control sections. The AADT on the freeway is 38500, but less than 500 on the service roads. All the roads have a bituminous concrete surface. Two hundred tonnes of commercially-produced CMA meeting FHWA specifications were purchased for the study. The CMA was applied by Ministry staff; the salt by a contractor.

During the winter of 1987-8, the same test sections were used and a short section of service road was added to investigate the effect of different application rates of CMA on deicing performance. An additional 180 tonnes of CMA were purchased from the same supplier as in 1986-7. The only significant difference between the CMA used in the two winters was that in 1987-8, the gradation was finer. Ministry staff applied both the CMA and the salt during the second winter.

The deicing effectiveness was determined through the observations of monitors who rated the condition of the roadway on an hourly basis. Standard reporting forms were developed for use by the monitors.

Observations with respect to storage, handling, and the condition of the equipment were made by the monitors and the patrol staff. The monitors, who were independent of both the Maintenance and the Research and Development Branches of the Ministry, were dedicated to the project and had no other duties.

The CMA was stored under cover in two sheds, one of which contained the neat material and the other, the CMA-sand mixture. The salt and salt-sand mixture were also stored under cover according to normal Ministry practice.

3. APPLICATION CRITERIA

Responsibility for determining when deicing chemicals would be applied rested with the patrol supervisor who based his decision on the condition of the roads and the Ministry's Maintenance Quality Standards (8).

The standard for the freeway requires that the accumulation of snow not normally be allowed to exceed 25 mm and that bare pavement be achieved as soon as reasonably possible. The standard for the service roads requires that snow not be allowed to accumulate beyond 70 mm but a snow-packed condition is acceptable. In practice, this meant that at the onset of a storm, CMA and salt were applied to the appropriate sections of the freeway at almost the same time. The specified application rate for salt was 130 kg per 2-lane km. (130 kg per 2-lane km is equal to 230 lb per lane mile). At the beginning of the 1986-7 winter, CMA was applied at a rate of 221 kg per 2-lane km (or 1.7 times

the rate for salt), but this rate was reduced later in the winter. Subsequent applications of CMA and salt during the storm were determined by the road conditions. In other words, if the pavement was not bare, a further application of deicing chemical was made at the specified rate. However, no attempt was made to make the same number of applications to the CMA and salt sections since the chemicals performed differently under different storm conditions. This means that although the specified application rate for CMA was (initially) 1.7 times that for salt, the total quantity of CMA used in any storm was not 1.7 times the quantity of salt since the number of applications usually differed. In some cases, there were more applications of CMA and sometimes less.

The initial ratio of 1.7 for the application rate of CMA to salt was taken from the calculation of theoretically equal deicing performance. The derivation was based on the requirement for equal amounts of NaCl and CMA ions in solution. The gram ions of 1 mole of MaCl and 1 mole of CMA (with a 3:7 molar ratio of Ca to Mg) then results in a NaCl to CMA ratio of 34.22/20.27 or 1.69.

The decision to use pure deicing chemical or a sand mixture on the freeway was also the responsibility of the patrol supervisor and was based on weather forecasts and his knowledge of local conditions. In general, when there was a reasonable expectation of maintaining bare pavement, neat CMA or salt was applied. At other times, particularly

during the most severe storms, or when temperatures were less than the optimum for deicing, or at night, sand mixtures were used to provide traction. Only sand mixtures were used on the service roads.

In 1986-7, the salt-sand mixture was a manufactured sand and 10% salt by mass. The target application rate was 570 kg per 2-lane km. The manufactured sand-salt mixture was used because it was in stockpile from the previous winter. The CMA-sand mixture was a mix of natural sand and 14% CMA by mass and was applied at a target application rate of 800 kg per 2-lane km. The CMA content and the application rate for the CMA-sand mixture were calculated from the quantities used in the first storm (the CMA was delivered a few hours before the storm and there was insufficient time to calibrate the spreader). Since it appeared to be effective, the application rate was not changed. In 1987-8, the salt-sand mixture was natural sand and 15% salt by mass, which is an established standard in the geographical area of the patrol. Less salt is used in manufactured sand mixtures than natural sand mixtures because the former is more abrasive and requires less salt to be effective. The CMA-sand mixture was the same as in the first winter.

Because of the very low traffic volumes on the service roads, these had the lowest priority within the patrol and sand mixtures were applied as equipment became available during a storm. The primary purpose of applying the sand mixtures to the service roads was to provide traction and no conscious attempt was made to provide bare pavement. Additional applications were made following plowing or if icy conditions developed.

For the second winter, four 0.5 km long sections of service road were added to the study and used to measure the effect of different application rates of CMA. The ratios of CMA to salt for the sections were 1.1, 1.3, 1.5, and 1.7. CMA was also applied to the road at both ends of the test sections to prevent contamination by salt.

4. HANDLING, STORAGE AND SPREADING CHARACTERISTICS, AND EFFECT OF EQUIPMENT

4.1 Dusting

The serious dusting problems reported in earlier studies (5,6) did not occur. It is important to note that the CMA used in this study was from a different supplier and the pellets were resistant to attrition. Some dusting occurred during loading operations, but not sufficient to require the operators to wear face masks. The amount of dusting of the CMA-sand mixture was greater after a period of prolonged storage (six weeks or more). Although the dusting did not constitute a serious handling problem, a well ventilated storage facility is needed.

4.2 Storage

The storage characteristics of the CMA were similar to those of salt though the angle of repose was somewhat greater. Occasionally, a light crust formed over the stockpile, but this was easily broken and the material became flowable when disturbed by the loader. The principal difference between CMA and salt was in the amount of caking which occurred on the paved apron outside the storage shed. During periods of precipitation, CMA would stick to the wet tires of the loader and was carried out of the shed. This material, together with that spilled

during loading resulted in a thick layer of caked CMA (sometimes up to 75 mm thick), sticking to the apron. This material was allowed to dry, at which time it could be picked up by the loader and was sufficiently friable to be mixed with sand and used as CMA-sand mix.

A fire in the wooden storage shed in December 1986 revealed some interesting properties of CMA. The fire was started by an electrical fault in the loader. The fire brigade was called and a large quantity of water was used to extinguish the fire. The water caused a crust to form on the CMA. This crust was impervious and protected the underlying material from water damage. The crust was approximately 20 mm thick except where water had flowed down the walls where it was as much as 150 mm thick. Upon drying, the crust was easily broken by a loader and was used for CMA-sand mix. The storage shed was not seriously damaged, although the loader was beyond repair.

4.3 Sticking

Upon contact with moisture, the CMA became sticky and adhered to the spreader hopper, the dispensing chute, and to the spinner. The spreader hopper was smaller than that normally used for salt and the relatively shallow slope of the hopper sides contributed to the amount of material sticking.

Neat salt is spread by dropping the material through the dispensing chute onto the centreline of the roadway. This was not possible with the CMA because spray from the truck tires caused the CMA to stick and plug the chute. The problem was overcome by discharging the CMA over a

slowly-rotating spinner. Although there was a build-up of material on the spinner, this did not affect its functional operation and the CMA was spread evenly in a band approximately 2 m wide along the centre-line. Salt-sand and CMA-sand mixtures were spread using the spinner operating at the normal rotation speed and there was no build-up of material.

In order to limit the amount of CMA sticking in the hopper between loads, either the hopper was emptied or the storage shed or the unit was stored in the equipment garage. Before reloading, the sides of the hopper were struck with a large rubber mallet to loosen the sticking material. The unit was washed following each storm, at which time material sticking to the hopper, chute, and spinner was easily removed. The salt unit was also washed between storms. These procedures were effective in controlling the amount of sticking which never became serious enough to interfere with normal equipment operations.

4.4 Effect on Equipment

An indication of the relative effects of CMA and salt on corrosion was obtained by observation of the spreader units after the first winter. On the unit used for CMA which was new at the start of the study, exposed metal remained shiny and free from rust. On the salt unit which was repainted prior to the study, the amount of paint lost was much greater, especially at seams and joints, and exposed metal was rusted. The CMA spinner remained free from rust, whereas the salt spinner became badly rusted.

5. DEICING PERFORMANCE DURING THE WINTER OF 1986-7

5.1 Overall Observations

Fifteen storms were encountered during the winter. The dates and the weather conditions associated with each storm are given in Table 1. A summary of the number of applications of deicing chemicals, the quantity applied to the QEW during each storm, and the time to achieve bare pavement (the bare and wet condition) are given in Table 2. Table 2 represents the sum of the deicer which was applied neat and the portion of deicer in the appropriate sand mixture. Complete details of when neat deicers and when sand mixtures were applied are given in a Ministry report (9).

After two months, the ratio of the application rates of CMA to salt ratio of 1.7 seemed excessive and the ratio was reduced to 1.5. The relatively small number of storms later in the winter precluded any conclusions being drawn with respect to the effectiveness of the different application rates.

Table 3 shows the quantity of deicing chemicals applied to the service roads. Since there was no attempt to maintain bare pavement, a comparison of performance similar to that reported in Table 2 for the QEW is not possible. However, the quantities shown were sufficient to maintain the low-volume roads to Ministry standards and there were no substantial differences between the condition of the CMA and the salt sections. The ratio of CMA-sand mixture to salt-sand mixture used over the entire season was 0.68. Since the CMA-sand mixture contained 14% CMA and the salt-sand mixture contained 10% salt, the ratio of CMA:salt used on the service roads was 0.95.

In general, most of the storms occurred when the temperature was between 0 and -5°C, which is typical of winter storm conditions in the Niagara Peninsula. Except for a single application of CMA, the coldest temperature at whichthe deicers were applied was -10°C. Within this range, temperature did not appear to affect the relative performance of salt and CMA. The storms ranged from a few hours to three days in duration, with the majority lasting less than one day. In some storms, more CMA than salt was used and in others, less. The ratio of CMA:salt usage over the entire winter was 1.2. Fewer applications of CMA than salt were made during the winter (though the application rate was greater) and the difference in the number of applications was most apparent during the storms of longer duration. The time to achieve bare pavement varied with the intensity of the storm but, with one exception, the performance of the CMA and salt were comparable and within 45 minutes of each other. High traffic volumes increased the clearing rate significantly, but the effect in the salt and CMA sections was the same.

Although the foregoing general observations are useful, it is equally revealing to examine the relative performance of the CMA and salt during individual storms.

5.2 Observations During Specific Storms

Storm No. 3, December 11-12, 1986

The time of application of the CMA and salt, and the condition of the roadway are shown in Figure 1(a). This storm can be considered a typical illustration of the relative performance of CMA and salt during

a storm of short duration. One application of pure material and one application of sand mixture was made at the same time to each section during the storm. The effect of each chemical on pavement condition was the same. The ratio of CMA used to salt was 1.9.

Storm No. 4, January 2-3, 1987

Details of deicer usage and pavement condition throughout the storm are given in Figure 1(b). This storm can be considered representative of the storms of longer duration with significant snowfall. There were six applications of salt, six applications of salt-sand mixture, four applications of CMA, and four of CMA-sand mixture. Roadway conditions during the storm were comparable except for a period of about three hours when the salt section became snow covered despite three applications of salt in rapid succession. Only one application of CMA in the same period was required to maintain track-bare pavement. The ratio of CMA to salt used during the storm was 1.1.

Storm No. 15, March 30 - April 2, 1987

This was the storm having the longest duration and heaviest snowfall of the winter. It was also exceptional in that it was the only time that the performance of the CMA and the salt was not comparable. Six applications of CMA and two of CMA-sand mixture were made over a 32 hour period. As shown in Figure 1(c), the roadway became snow covered for a period of approximately one hour on two occasions, but was otherwise track-bare or better. By contrast, the salt section became snow packed such that the application of salt was suspended and maintenance consisted of plowing. Three applications of salt were required after the

last application of CMA. The final application of salt was made at 8:00 am on April 2 and is not included in Figure 1(c). The salt section did not become track-bare until about 19 hours after the CMA section reached the same condition; bare and dry conditions were not achieved in the salt section until 11 hours after the CMA section. Since CMA continued to be applied throughout the storm, the quantity used was 2.6 times as much as the salt.

An attempt was made to compare the performance of the CMA and the salt using standard statistical techniques. Variables considered included the time to clear the snow or ice, the quantity of deicer used, and the effect of weather conditions. However, because the patrol personnel were instructed to do what was necessary to maintain safe driving conditions, different quantities of the two deicers were spread at different times, and the standard analytical techniques could not be used.

5.3 Effect of Wind During Application

There was no significant difference between the behaviour of salt and CMA under windy conditions. It was not found necessary to cover the loads with a tarpaulin. Under strong wind condition, both deicers were blown after discharge from the hopper, resulting in uneven application. The untreated areas required a further application of deicer. The combined effect of the wind in causing unevenapplication and in lowering pavement surface temperatures reduced the effectiveness of both deicers by about the same degree.

5.4 Retention on the Road Surface

The spreading characteristics of the two materials were similar and, although the CMA was lighter, the particles did not bounce appreciably more than salt particles. Once on the road surface, the two deicers behaved differently. When applied to a moist pavement, the CMA stuck to the pavement surface. Where ice and snow were present, the CMA stuck to the ice and snow and the pellets gradually penetrated to the roadway surface. The action of traffic embedded the material in the road surface where the pellets continued to dissolve. As the roadway surface dried, the excess CMA remained bonded to the pavement until there was further precipitation. The salt did not bond to the pavement to the same degree with the result that it was more easily removed from the road surface by traffic, wind, and any subsequent plowing.

The retention of the CMA on the pavement explains two important differences in the performance of CMA and salt. Firstly, it was found that CMA was relatively more effective during the longer storms. As the storm progressed, fewer applications of CMA were needed and the ratio of CMA to salt used was much less during the storms of two to three days duration than in those which lasted a few hours. Secondly, the CMA had a residual effect from one storm to another with the result that the ratio of CMA to salt usage tended to decrease through January and February. The presence of CMA embedded in the pavement meant that at the onset of a storm, a solution formed and prevented icing of the roadway surface. Observations of the pavement up to two weeks after the last application revealed particles of CMA embedded in the surface. The CMA which was retained on the pavement did not attract

moisture and there was no tendency for the pavement to ice as reported in an earlier study (5). An extended mild period, during which there were several periods of rain, meant that this residual effect was not apparent during the final storm of the winter.

5.5 Penetration Through Snow Pack

The two deicers reacted differently when applied to a snow- packed road surface. The salt formed a brine on the surface of the snow pack. Conversely, the CMA pellets dissolved more slowly and penetrated through the snow pack to the road surface. This was particularly apparent on the service roads. Following plowing, sand and CMA could be found adhering to the pavement. In the salt control section, the sand and salt mixture remained suspended within the snow pack and was scraped off by the plow. The penetration of the CMA meant that it was more effective than salt in breaking up snow pack. Another characteristic of the CMA was the creation of a pothole effect in the snow pack. The rough surface increased traffic noise with the result that drivers reduced speed. By contrast, the salt tended to glaze the surface, creating an illusion of wet pavement, especially at night.

5.6 Pavement Colouration

Following each storm, the pavement in the salt control section was stained white and the visibility of the pavement markings was reduced. Between storms, traffic, together with any rain which fell, reduced the amount of staining.

The CMA section showed little change in colour throughout the winter.

There was a slight tea-coloured stain between the wheet tracks and between the traffic lanes, but this did not affect the visibility of the pavement markings.

5.7 Acceptance by Patrol Staff

One of the objectives of the study was to determine the impact of the use of CMA on normal patrol operations. Consequently, the reactions of the patrol staff were important. Despite the introduction of a new deicer, the patrol staff continued to be responsible for the condition of the roadway and applied material as needed, with the result that the ratio of CMA to salt varied from from storm to storm. As the winter progressed, the patrol became comfortable with the CMA and confident it would perform as required. Minor irritations such as sticking on the paved apron and inside the spreader were resolved quickly by patrol staff at their initiative. Following the full winter's field trial, the overall response of the patrol staff to CMA was favourable.

6. DEICING PERFORMANCE DURING THE WINTER OF 1987-8

6.1 Overall Observations

The 1986-7 winter was milder than average and the field trial was continued in 1987-8 mainly to study the environmental effects under more concentrated and prolonged exposure. The only changes in the study design and the monitoring of operational characteristics were:

- the deicers in both the CMA and the control sections were applied by Ministry staff;
- the salt-sand mixture consisted of natural sand and 15% salt by mass.

- the sections having different application rates for the CMA were added.

Following the analysis of the results from the first winter, the decision was made to use an application ratio of 1.4 at the start of the 1987-8 winter. However, in late January, the patrol staff expressed the view that the performance of the CMA was less than expected and the ratio was increased to 1.7 for the remainder of the winter. The application rates of the CMA-sand and the salt-sand mixtures used in 1987-8 were the same as those used in 1986-7.

Twenty separate storms were identified during the 1987-8 winter, but many of these were very short. The dates of the storms and the weather conditions associated with them are given in Table 4. Summaries of the data for 1987-8, corresponding the Tables 2 and 3 for 1986-7, are given in Tables 5 and 6.

During Storm No. 20, an equipment breakdown made it necessary to apply CMA to .aomtaom safe driving conditions on the salt section of the QEW. As a result, the quantities of deicer used in Storm No. 20 are not reported in Table 5, nor included in the calculation of the total quantities applied during the winter.

Table 5 gives the number of applications, the quantity of deicer applied, and the time to achieve bare pavement for the QEW test sections. A major difference between the results of 1986-7 and 1987-8 is that in the first winter, the number of applications of CMA was

usually less than that of salt in each storm. In the second winter, the number of applications of CMA often exceeded the number of salt applications. This occurred because a truck was dedicated to the short CMA section so that, in all except the worst storm conditions, CMA could be applied when needed. The salt section was longer and more distant from the patrol yard so that not only was the frequency of applying salt less than CMA, but a heavier application than the standard sometimes had to be made.

The occurrence of numerous short storms during which it was often problematical whether deicing chemicals would be needed also made it more difficult to analyze the results from the second winter than the first. For the purpose of this study, a storm was not defined from meteorological data but simply by conditions which resulted in the application of a deicer to the QEW. The separation of one storm from another was also somewhat arbitrary, but was characterized by a change in weather conditions and a break in the application of deicers. Using these definitions, there were several "storms" during which there were one or two applications of deicing chemicals, but which could be described better as squalls. In these cases, the patrol supervisor had to decide whether the road would remain serviceable without deicing or whether it was more prudent to apply a deicer. Since the CMA and the salt were not necessarily applied at the same time, and weather conditions often changed rapidly during these "storms", the ratio of the deicers used in short storms can be misleading. Because the response time to the CMA section was less than to the salt section, this resulted in more CMA being applied in short storms during which

the weather conditions improved. Conversely, when the weather conditions deteriorated, less CMA was used because of its more timely application and additional applications of salt were sometimes needed to bare the pavement.

Another factor which was more noticeable in 1987-8 than 1986-7 was the occurrence of small drifts in the test sections. Under such conditions, sand mixes were applied selectively to the problem areas (often called "spot sanding") but the quantities used were calculated as an average over the appropriate test section. This explains why the quantities applied in Table 5 were sometimes less than the prescribed application rates, as, for example, in Storm Nos. 6 and 16.

To the extent that overall observations can be drawn from the experiences in short storms, the relative performance was the same as that in short storms in the first winter, i.e. roadway conditions were comparable throughout the storm, but considerably more CMA than salt was used.

Although the ratio of deicers used in individual short storms can be misleading, the anomolies which resulted from different times of application and drifting conditions tend to cancel out over an entire winter. This averaging effect, together with the fact that much larger quantities of deicers are used in the longer storms, mean that the ratio of the total quantities of CMA and salt used is considered to be a reliable indicator of relative performance. The ratio of CMA to salt used on the QEW sections in 1987-8 was 1.4 compared to 1.2 in 1986-7.

In all other respects, the relative performance of the two deicers in terms of both application and effectiveness during the two winters was very similar.

Table 6 gives the quantities of deicers applied to the service roads and shows that considerably more CMA-sand mixture than salt-sand mixture was used. However, the difference is more a reflection of the operational procedures than an indication of relative performance. The CMA truck could carry sufficient CMA-sand mixture to service both the QEW and the service roads so that sand mix was usually applied to the CMA section early in the storm. After servicing the QEW, the salt truck had to return to the yard to pick up another load of sand mix for the service roads. During severe storms, the truck made another application to the QEW, rather than the service roads, since priority had to be given to maintaining the freeway. In the longer storms there was a substantial difference between the quantity of CMA-sand mixture and salt-sand mixture applied, but a direct comparison is not possible because the CMA section was maintained to a higher standard than the salt section. A much more comparable level of service was provided on the service roads during the first winter and comparison of the data in Table 3 is more valid than comparisons drawn from Table 6.

As in the case of the results from the first winter, it is also instructive to examine the relative performance of the CMA and salt during individual storms during 1987-8.

6.2 Observations During Specific Storms

The experience in short storms has already been discussed and it is illustrative to take two longer storms, one in which the salt section was in slightly better condition during the storm and the other in which the CMA section was slightly better, as being representative of the relative performance of the two deicers.

Storm No. 4, December 28-29, 1987

The storm began at 8:00 pm on December 28 and lasted for 17 hours. The temperature was -3°C at the beginning of the storm and fell to -7°C by the time precipitation ended. The road conditions deteriorated rapidly and icy conditions developed in the first hour. The first application was neat deicer, but as the temperature fell, sand mixtures were used throughout the night. Neat deicers were again applied on the morning of December 29 to remove the remaining slushy sections from the pavement. Details of the usage of the deicers and the condition of the pavement are given in Figure 2(a). The salt section was in slightly better condition than the CMA section for most of the storm and bare, dry pavement was achieved two hours sooner. The ratio of the quantities of CMA and salt used during the storm was 1.1.

Storm No. 13, February 11-12, 1988

Storm No. 13 was the worst storm of the winter, beginning at 2:00 am on February 11 and lasting for 36 hours. During the storm there were eight applications of CMA and five of CMA-sand mixture, seven applications of salt, and four of salt-sand mixture. Temperatures ranged from -10°C to -1°C. The condition of the roadway is illustrated

in Figure 2(b). Except for brief periods when slushy sections developed, the roadway was maintained in a track bare condition or better throughout the storm. The condition of the CMA section was slightly, though not significantly, better than the salt section. The ratio of the quantities of CMA and salt used in the storm was 1.6.

6.3 Observations of Test Sections with Different Application Rates

The experiment designed to determine the optimum application rate of CMA was not successful because the site chosen was not the most appropriate and the need to give priority to servicing the QEW meant that plowing and deicing could not be done at the optimum time. neat CMA was applied to the test sections when neat CMA was used on the QEW and observations were only made when neat CMA was used. This was done because it was not practical to have four CMA-sand mixtures with different percentages of CMA for such short sections, but the result was that only a limited amount of data could be collected. In a typical storm, CMA would be applied at the prescribed rates as early as possible in the sotrm. However, snow would accumulate on the roadway because of the very low traffic volumes during most of the day and would not be plowed until equipment became available from the freeway. By the time the road was plowed, the condition of the four test sections was very similar. The interpretation of the results was also complicated by the fact that most of the traffic was concentrated at the beginning and end of the working day and the condition of the roadway was strongly influenced by the relative times of deicer application, plowing, and peak traffic. There were indications that

the sections having the two higher application rates were, at times, in better condition that the other two sections, but it was not possible to isolate the effect of the different application rates and firm conclusions could not be made.

7. COSTS

Although an analysis of costs was not within the scope of the current study, it is important to recognize that CMA is only available in limited quantities and at a very high cost. In 1986-7 the CMA was purchased at $500 U.S. per ton f.o.b. plant. The cost at the patrol yard, including freight, duties and taxes was $1050 (Can.) per tonne. The cost of salt was $29.41 (Can.) per tonne f.o.b. patrol yard. The costs in 1987-8 were $1060 and $30.20 respectively.

A comprehensive analysis of the financial implications of using CMA has been made in a separate study (10).

8. CONCLUSIONS

1. The CMA was used on the test sections throughout two winters. Under the conditions of use, the performance of the CMA was similar to that of salt in achieving bare pavement.
2. The initial application rate of CMA of 1.7 times that of salt appeared excessive and an application rate of 1.4 appeared insufficient, but the optimum application rate was not determined.
3. The ratio of the total quantities of CMA and salt used on the freeway test sections was 1.2 in 1986-7 and 1.4 in 1987-8.

4. CMA was retained on the pavement longer than salt with the result that it was relatively more effective in longer storms. There was also a residual effect of CMA from one storm to another such that the ratio of CMA to salt used decreased as the winter progressed. This effect was more apparent in 1986-7 than in 1987-8.
5. The storage and handling characteristics of CMA were comparable to those of salt.
6. The use of CMA did not require changes in equipment and only small changes in normal maintenance procedures. The tendency of the material to stick to equipment and loading areas was a minor inconvenience. Patrol staff readily accepted the CMA.
7. The salt spreader unit exhibited significant corrosion; the CMA unit remained free from rust.

9. FUTURE RESEARCH

The results from the two winters' field trials have shown that CMA is an effective deicer on both freeway and low-volume roads under the relatively mild conditions of the Niagara Peninsula.

Further research is required to determine the optimum application rate for CMA and to evaluate its performance under conditions of lower temperatures, higher snowfall, and on two-lane highways with traffic volumes more representative of highways in Ontario.

10. REFERENCES

1. Dunn, S.A., and Schenk, R.J., "Alternative Highway De-Icing Chemicals", Report No. FHWA-RD-79-109, Federal Highway Administration (1980).

2. Winters, G., "Environmental Evaluation of Calcium Magnesium Acetate as an Alternative Highway Deicing Chemical", California Department of Transportation (1983).

3. Chollar, B.H., "FCP Annual Progress Report, Year Ending September 30, 1984, Project 3C - Calcium Magnesium Acetate (CMA) as an Alternate Deicer", Federal Highway Administration (1984).

4. Pianca, F., "An Assessment of CMA as an Alternative De-Icer", Report No. ME-84-02, Ontario Ministry of Transportation and Communications, 22 pp (1984).

5. Ernst, D.D., Demich, G., and Wieman, T., "CMA Research in Washington State", Washington Department of Transportation, 19 pp (1984).

6. Defoe, J.H., "Evaluation of Calcium Magnesium Acetate as an Ice Control Agent", Research Report No. R-1238, Michigan Transportation Commission, 28 pp (1984).

7. Pianca, F., Carter, K.C., and Sedlak, H., "A Comparison of Concrete Scaling Caused by Calcium Magnesium Acetate and Sodium Chloride in Laboratory Tests", Report MI-108, Ontario Ministry of Transportation and Communications, 19 pp (1987).

8. Maintenance Manual Operating Instructions, Volume 4, Ministry of Transportation and Communications.

9. Manning, D.G., and Crowder, L.W., "A Comparative Field Study of Calcium Magnesium Acetate and Rock Salt During the Winter of 1986-1987", Report No. ME-87-16, Ontario Ministry of Transportation and Communications, 48 pp (1987).

10. Bacchus, A., "Financial Implications of Salt vs. CMA as a Deicing Agent", Report No. ME-87-23, Ontario Ministry of Transportation and Communications, 31 pp (1987).

TABLE 1: SUMMARY OF STORMS DURING THE WINTER OF 1986-7

STORM No.	DATE	AVERAGE TEMPERATURE °C	SNOW cm	RAIN mm	AVERAGE WIND SPEED km/hr
1	NOV 20-21/86	-1.7	14.0	0.0	10.00
2	DEC 8/86	-4.0	7.0	13.4	12.00
3	DEC 11/87	-1.0	0.4	0.6	8.00
4	JAN 2/87	-1.0	9.2	0.6	10.00
5	JAN 10-12/87	-1.9	1.0	0.4	13.00
6	JAN 18/87	-1.0	5.4	0.0	11.00
7	JAN 19-20/87	-4.0	15.0	0.0	10.00
8	JAN 22/87	-3.0	2.0	0.0	18.00
9	JAN 26/87	-7.0	1.0	0.0	6.00
10	JAN 30/86	-3.0	4.8	0.0	8.00
11	FEB 2-3/87	0.0	1.8	0.0	10.00
12	FEB 8/87	-9.3	2.0	2.0	34.00
13	FEB 14/87	-10.0	0.8	0.0	14.00
14	FEB 16/87	-1.4	1.0	0.0	6.00
15	MAR 30-APR 1/87	-2.8	16.5	0.0	10.00

TABLE 2: COMPARISON OF QUANTITIES AND DEICING TIMES FOR CHEMICALS APPLIED TO THE QEW IN 1986-7

	CMA			SALT		
STORM No.	No. OF APPLIC.	kg/ 2-LANE km APPLIED	TIME TO BARE PAVEMENT H	NO. OF APPLIC.	kg/ 2-LANE km APPLIED	TIME TO BARE PAVEMENT H
1	8	1270	23.50	11	2000	23.50
2	5	1830	14.50	8	1050	14.50
3	2	420	2.00	2	220	2.50
4	8	1520	19.50	12	1420	19.75
5	7	1530	41.00	8	1230	41.00
6	4	1090	6.50	7	1000	6.50
7	5	1340	20.75	9	810	20.75
8	3	770	6.25	3	510	6.25
9	2	170	2.50	4	220	2.50
10	7	1460	23.75	11	1770	23.75
11	2	310	15.00	1	120	15.00
12	2	330	10.00	1	220	10.50
13	2	230	8.25	1	100	9.00
14	2	160	9.00	1	400	9.00
15	8	1450	20.00	9	560	34.00
TOTAL	67	13880		88	11630	

APPLICATION RATIO, CMA : SALT 1.2

TABLE 3: QUANTITIES OF DEICING CHEMICALS APPLIED TO THE SERVICE ROADS IN 1986-7

STORM NO.	CMA		SALT	
	NO. OF APPLICATIONS	kg/2-LANE km OF MIX APPLIED	NO. OF APPLICATIONS	kg/2-LANE km OF MIX APPLIED
1	4	2690	3	4360
2	3	1640	3	2430
3	1	740	1	1000
4	3	1270	4	3520
5	3	1670	4	3650
6	2	1740	2	2230
7	2	1520	2	1710
8	1	1420	1	1090
9	2	1230	1	1140
10	3	2290	3	2330
11	1	760	1	1140
12	2	1470	2	1640
13	0	0	0	0
14	1	760	1	960
15	2	890	2	2270
TOTAL	30	20090	30	29470

APPLICATION RATIO, CMA MIX : SALT MIX = 0.68

CORRECTED APPLICATION RATIO, CMA : SALT = 0.95

TABLE 4: SUMMARY OF STORMS DURING THE WINTER OF 1987-8

STORM NO.	DATE	AVER. TEMP. °C	SNOW cm	RAIN mm	AVERAGE WIND km/h
1	DEC 4/87	-0.1	8.4	0.0	5.0
2	DEC 5/87	-0.4	0.6	0.0	---
3	DEC 15/87	-2.7	5.2	22.0	---
4	DEC 28-29/87	-5.5	8.6	9.0	25.0
5	JAN 4/88	-3.5	0.8	0.0	10.0
6	JAN 14/88	-11.0	1.4	0.0	4.0
7	JAN 21/88	-1.2	0.4	0.2	7.0
8	JAN 23/88	-2.5	2.0	0.0	2.0
9	JAN 25-26/88	-4.5	4.4	0.0	5.0
10	FEB 2-4/88	-3.2	16.2	5.6	10.0
11	FEB 7-8/88	-9.0	1.2	0.0	15.0
12	FEB 9/88	-8.0	0.8	0.0	5.0
13	FEB 11-12/88	-5.0	10.0	0.0	17.0
14	FEB 13/88	-8.0	0.0	6.4	7.0
15	FEB 19/88	-1.0	0.0	12.2	2.0
16	FEB 26/88	-5.0	0.8	0.0	18.0
17	FEB 27/88	-2.0	0.6	0.0	18.0
18	FEB 29/88	0.5	0.2	0.0	12.0
19	MAR 14/88	-2.2	1.2	0.0	5.0
20	MAR 19-20/88	-2.0	4.0	1.2	5.0

TABLE 5: COMPARISON OF QUANTITIES AND DEICING TIMES FOR CHEMICALS APPLIED TO THE QEW IN 1987-8

	CMA			SALT		
STORM No.	No. OF APPLIC.	kg/ 2-LANE km APPLIED	TIME TO BARE PAVEMENT H	NO. OF APPLIC.	kg/ 2-LANE km APPLIED	TIME TO BARE PAVEMENT H
1	1	170	0.75	1	130	0.75
2	2	350	2.00	1	130	2.00
3	2	290	15.75	2	300	15.75
4	8	1060	17.75	6	980	17.25
5	2	210	1.00	2	280	1.75
6	1	100	4.00	1	90	4.00
7	1	180	N/A	1	150	N/A
8	3	540	4.75	3	480	4.75
9	11	1530	25.50	5	750	25.50
10	11	1700	61.00	10	1470	61.00
11	4	630	13.00	3	310	12.50
12	4	730	8.50	3	390	8.00
13	13	2100	31.25	11	1270	31.25
14	5	340	N/A	6	380	N/A
15	2	310	3.50	1	150	3.50
16	1	110	N/A	1	50	N/A
17	2	310	2.50	2	220	2.50
18	1	200	0.50	1	130	0.50
19	1	180	N/A	1	150	N/A
TOTAL	75	11040		61	7810	

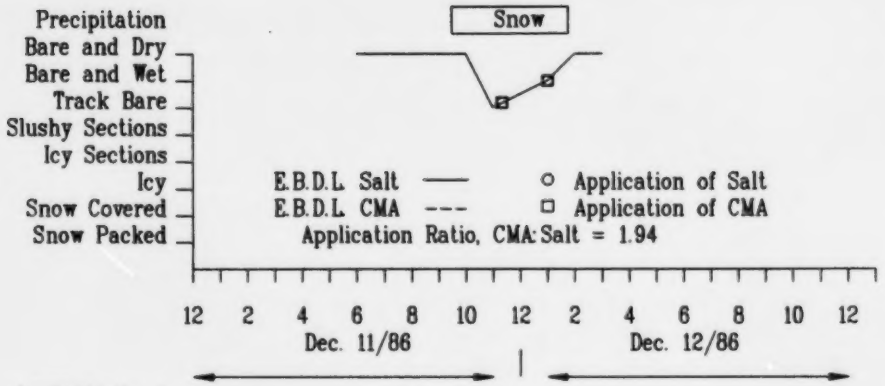
APPLICATION RATIO, CMA MIX : SALT MIX = 1.4
N/A NOT APPLICABLE - LOCALIZED DRIFTING ONLY

TABLE 6: QUANTITIES OF DEICING CHEMICALS APPLIED TO THE SERVICE ROADS IN 1987-8

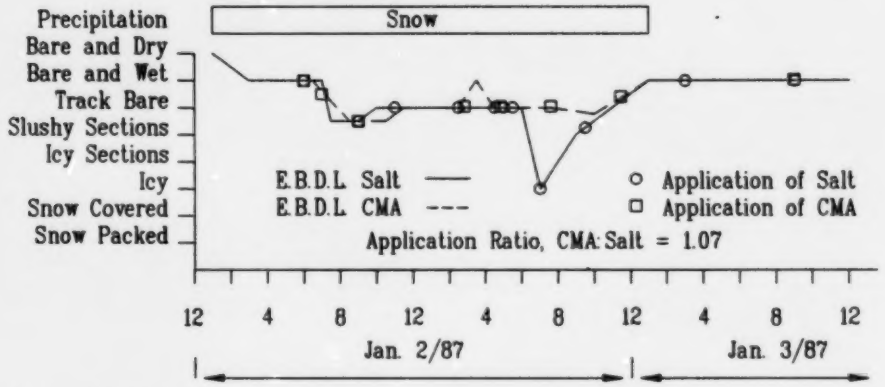
STORM NO.	CMA		SALT	
	NO. OF APPLICATIONS	kg/2-LANE km OF MIX APPLIED	NO. OF APPLICATIONS	kg/2-LANE km OF MIX APPLIED
1	1	250	0	0
2	1	720	1	500
3	1	700	1	500
4	3	1710	3	1160
5	1	720	1	600
6	1	720	1	780
7	0	0	0	0
8	3	1720	2	780
9	2	1440	3	1500
10	5	3810	5	2400
11	1	790	1	600
12	0	0	0	0
13	3	2140	3	1280
14	2	1510	1	500
15	1	790	0	0
16	0	0	0	0
17	0	0	1	40
18	0	0	0	0
19	0	0	0	0
20	2	1350	1	500
TOTAL	27	18370	24	11140

APPLICATION RATIO, CMA MIX : SALT MIX = 1.6

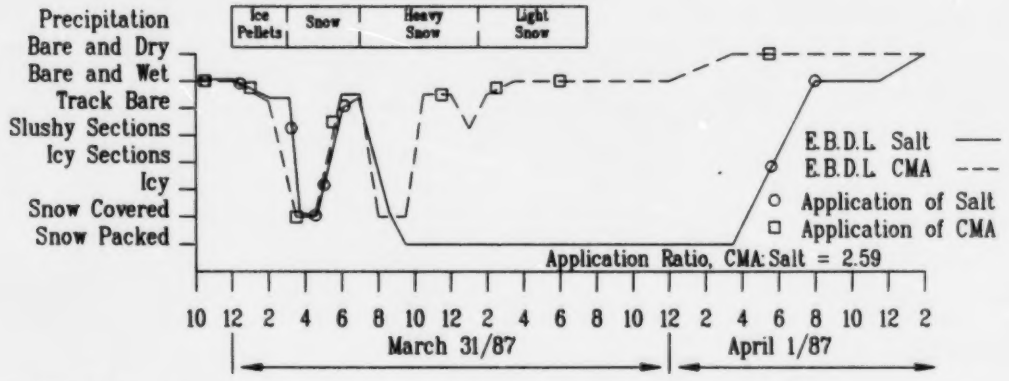
CORRECTED APPLICATION RATIO, CMA : SALT = 1.5



a) STORM No. 3

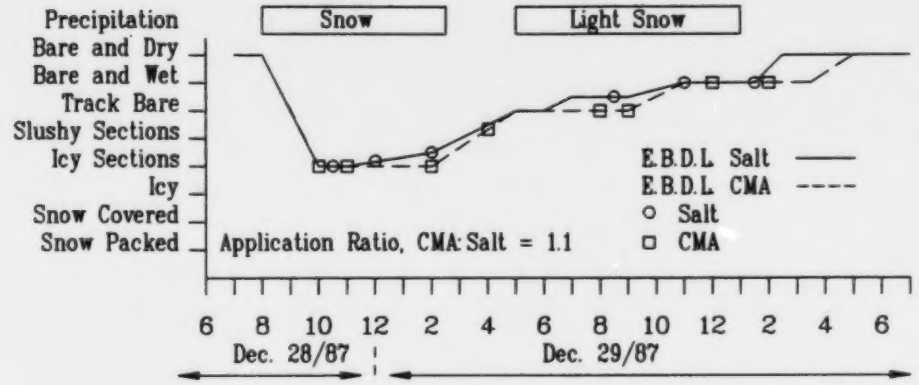


b) STORM No. 4

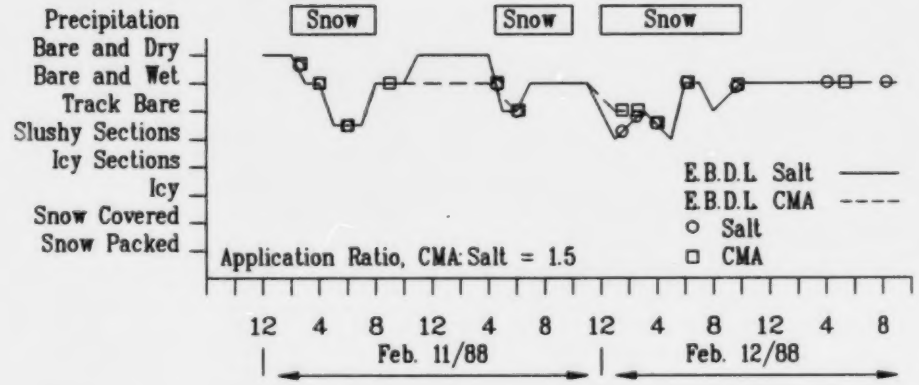


c) STORM No. 15

Figure 1: Roadway Conditions During Storm Nos. 3, 4 and 15 in 1986-7



a) STORM No. 4



b) STORM No. 13

Figure 2: Roadway Conditions During Storm Nos. 4 and 13 in 1987-8

APPENDIX A

APPLICATIONS OF DEICERS DURING THE WINTER OF 1986-7

TABLE A1: APPLICATION OF DEICING CHEMICALS TO QEW

STORM NO.	DATE	TIME	TEMP °C	SALT kg per 2-lane km	SALT SAND kg per 2-lane km	CMA kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO (1) CMA:SALT
1	NOV.20/86	8:50 am	-1			378.00		
		9:20 am			1091.00			
		10:25 am			1091.00			
		10:50 am					672.00	
		11:20 am		500.00				
		3:35 pm	-2		1091.00			
		4:00 pm					672.00	
		4:45 pm			1091.00			
		5:10 pm			851.00			
		7:15 pm					672.00	
		7:30 pm			1702.00			
		10:00 pm		375.00			672.00	
	NOV.21/86	2:05 am		127.00				
		3:15 am			1332.00		672.00	
		5:05 am			1702.00		1512.00	
		6:40 am	-2				1512.00	
	TOTAL			1002.00	9951.00	378.00	6384.00	0.64
2	DEC.8/86	4:55 pm			1000.00			
		5:05 pm	-7				740.56	
		6:15 pm		178.04				
		6:30 pm	-7	118.87		539.99		
		8:20 pm	-6	118.87		539.99		
		8:40 pm	-6	148.59				
	DEC.9/86	2:30 am	-3				740.56	
		3:35 am	-1		1000.00			
		5:05 am	-1	237.74				
		5:25 am				539.99		
		9:40 am	-1		500.00			
	TOTAL			802.11	2500.00	1619.97	1481.12	1.74
3	DEC.11/86	11:15 pm	2		1000.00		711.56	
	DEC.12/86	1:00 am	0	118.69		324.01		
	TOTAL			118.69	1000.00	324.01	711.56	1.94

TABLE A1 (continued)

STORM NO.	DATE	TIME	TEMP °C	SALT kg per 2-lane km	SALT SAND kg per 2-lane km	CMA kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO (1) CMA:SALT
4	JAN.2/87	6:00 am	-2	108.11		324.01		
		7:10 am	-2			324.01		
		7:30 am	-2	216.22				
		8:45 am	0		675.68			
		9:50 am	-2				249.95	
		10:50 am	-2	108.11				
		2:40 pm	-2	108.11		162.01		
		5:10 pm	0		960.00			
		5:20 pm	0				874.83	
		5:30 pm	0	237.39				
		5:50 pm	0		960.00			
		7:35 pm	0		960.00		874.76	
		9:30 pm	0	178.04		324.01		
	JAN.3/87	3:00 am	0		595.24			
		9:30 am	0		500.00			
		10:10 am	0				740.60	
	TOTAL			955.98	4650.92	1134.04	2740.14	1.07
5	JAN.10/87	2:55 am	-3		800.00		740.56	
		3:50 am	-3	178.04				
		4:20 am	-3			323.99		
		5:30 am	-3			323.99		
		5:45 am	-3		800.00			
		6:25 am	-3	178.04				
		8:10 am	-1	178.04		323.99		
	JAN.11/87	3:55 am	-1	178.04				
		4:30 am	-1				462.85	
		5:10 am	-1	237.74				
		6:35 pm	-1	118.87				
		7:10 pm	0			323.99		
		8:05 pm	0				462.85	
	TOTAL			1068.77	1600.00	1295.96	1666.26	1.24
6	JAN.18/87	4:30 am	-2	118.87				
		5:00 am	-2	142.86		323.99		
		6:00 am	-2	118.87				
		7:00 am	-2	142.86		323.99		
		7:40 am	-1	59.44				
		8:10 am	-1	178.31				
		10:00 am	0	237.74		323.99		
		1:55 pm	1				874.79	
	TOTAL			998.95	0.00	971.97	874.79	1.10

TABLE A1 (continued)

STORM NO.	DATE	TIME	TEMP °C	SALT kg per 2-lane km	SALT SAND kg per 2-lane km	CMA kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO (1) CMA:SALT
7	JAN.19/87	1:15 pm	-3		1090.90			
		2:00 pm	-3	118.69		323.99		
		3:15 pm	-3		500.00		740.60	
		5:35 pm	-3		625.00			
		6:20 pm	-5		444.44		583.22	
		6:55 pm	-6		500.00			
		9:40 pm	-7		960.00			
		10:16 pm	-7				740.60	
	JAN.20/87	3:30 am	-10		1000.00		583.22	
		9:00 am		176.47		647.99		
	TOTAL			295.16	5120.34	971.98	2647.64	1.66
8	JAN.22/87	6:50 pm	-3	178.31		323.99		
		9:35 pm	-3		960.00		874.79	
		11:30 pm	-3	237.04		323.99		
	TOTAL			415.35	960.00	647.98	874.79	1.51
9	JAN.27/87	2:50 am	-7		1086.48			
		3:10 am	-7		543.48			
		3:45 am	-7				740.56	
		4:25 am	-7				462.85	
		4:30 am	-7		595.24			
	TOTAL				2225.20		1203.41	0.76
10	JAN.30/87	12:00 am	-3	178.04		323.99		
		2:36 am	-3	178.04				
		3:00 am	-3			162.00		
		4:55 am	-3	237.39		323.99		
		6:10 am	-2		600.00		874.79	
		6:14 am	-2					
		8:50 am	2	88.24		162.00		
		6:15 pm	0	118.87				
		6:40 pm	0			243.00		
		8:10 pm	-1	118.87				
		10:10 pm	-1		1000.00		874.79	
	JAN.31/87	4:15 am	-1	300.00				
		6:00 am	-1	377.36				
		10:40 am	-1	14.86				
	TOTAL			1611.67	1600.00	1214.98	1749.58	0.82

TABLE A1 (continued)

STORM NO.	DATE	TIME	TEMP °C	SALT kg per 2-lane km	SALT SAND kg per 2-lane km	CMA kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO (1) CMA:SALT
11	FEB.2/87	11:25 pm	0	118.87			709.79	
	FEB.3/87	1:17 am	0			205.68		
	TOTAL			118.87	0.00	205.68	709.79	2.57
12	FEB.8/87	3:20 pm	-4	117.65		231.95		
		5:00 pm	-7		1000.00		711.52	
	TOTAL			117.65	1000.00	231.95	711.52	1.52
13	FEB.14/87	8:45 am	-10				835.02	
		3:00 pm	-10		1000.00			
		3:15 pm	-10				835.02	
	TOTAL			0.00	1000.00	0.00	1670.04	2.34
14	FEB.16/87	4:35 am	-19				711.52	
		10:40 am	-10	400.00			412.36	
	TOTAL			400.00	0.00	0.00	1123.88	0.39
15	MAR.30/87	10:20 pm	0	118.17		216.00		
	MAR.31/87	1:10 am	-1		472.67	177.88		
		2:40 am	-1		177.25			
		3:30 am	-2			216.00		
		4:15 am	-2		89.55			
		5:00 am	-2		235.29			
		5:40 am	-2			216.00		
		6:20 am	-2		119.40			
		11:45 am	-3				863.99	
		2:15 pm	-3			133.41		
		5:00 pm	-4			323.99		
	APR.1/87	6:10 am	-6	119.40			355.76	
		7:55 am	-1		960.00			
	APR.2/87	8:00 am		119.40				
	TOTAL			356.97	2054.16	1283.28	1219.75	2.59

(1) CMA :SALT RATIO FORMULA

$$\frac{\text{(kg of CMA applied per 2-lane km)} + \text{(kg of CMA SAND MIX applied per 2-lane km} \times 0.14)}{\text{(kg of SALT applied per 2-lane km)} + \text{(kg of SALT SAND MIX applied per 2 lane km} \times 0.10)}$$

EXAMPLE STORM 1

$$\frac{(378) + (6384 \times 0.14)}{(1002) + (9951 \times 0.10)} = 0.64$$

TABLE A2: APPLICATION OF DEICING CHEMICALS TO SERVICE ROADS

STORM NO.	DATE	TIME	TEMP °C	SALT SAND kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO (2) CMA MIX :SALT MIX
1	NOV.20/86	10:30 am	-2		672.00	
		4:00 pm	-2		672.00	
		5:45 pm	-2	1091.00		
		6:20 pm	-2	1091.00		
		7:15 pm	-2		672.00	
	NOV.21/86	1:30 am	-2	2182.00		
		3:15 am	-2		672.00	
	TOTAL			4364.00	2688.00	0.62
2	DEC.8/86	5:05 pm	-7		740.55	
		6:30 pm	-7	1136.30		
	DEC.9/86	2:30 am	-3	1136.30	740.55	
		10:20 am	-1		161.99	
		11:30 am	-1	160.00		
	TOTAL			2432.60	1643.09	0.68
3	DEC.11/86	11:15 pm	2	1000.00	742.12	
	TOTAL			1000.00	742.12	0.74
4	JAN.2/87	6:20 am	-2	675.70		
		9:30 am	-2		255.70	
		10:55 am	-2	568.20		
		12:25 am	-2		255.70	
		2:55 pm	-2	1136.40		
	JAN.3/87	9:50 am	0	1136.40		
		10:10 am	0		757.60	
	TOTAL			3516.70	1269.00	0.36
5	JAN.10/87	2:55 Pm	-2		740.56	
		10:50 pm	-2	1136.40		
	JAN.11/87	1:25 am	-2	545.50		
		7:10 am	0	1090.90		
		4:30 pm	0		462.85	
		8:05 pm	0	880.00	462.85	
	TOTAL			3652.80	1666.26	0.46
6	JAN.18/87	4:30 am	-2	1136.40		
		6:00 am	-2		1033.10	
		1:55 pm	1	1090.90	708.00	
	TOTAL			2227.30	1741.10	0.78

TABLE A2 (continued)

STORM NO.	DATE	TIME	TEMP ^{o}C	SALT SAND kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO (2) CMA MIX :SALT MIX
7	JAN.19/87	3:15 pm	-3		757.60	
		10:16 pm	-7		757.60	
	JAN.20/87	1:55 am	-10	1136.40		
		2:50 am	-10	568.20		
	TOTAL			1704.60	1515.20	0.89
8	JAN.22/87	8:20 pm	-3		1416.20	
		9:30 pm	-3	1090.90		
	TOTAL			1090.90	1416.20	1.30
9	JAN.27/87	3:45 am	-7		757.60	
		4:10 am	-7	1136.40		
		4:25 am	-7		473.50	
	TOTAL			1136.40	1231.10	1.08
10	JAN.30/87	12:25 am	-3	648.60		
		12:55 am	-3		708.00	
		6:10 am	-2	545.50	708.00	
		6:55 pm	-1	1136.40		
		7:40 pm	-1		874.10	
	TOTAL			2330.50	2290.10	0.98
11	FEB.2/87	11:25 pm	0	1136.40	757.60	
	TOTAL			1136.40	757.60	0.67
12	FEB.8/87	3:40 pm	-4	500.00		
		5:20 pm	-4		757.60	
	FEB.9/87	1:30 am	-5	1136.40		
		1:50 am	-5		708.00	
	TOTAL			1636.40	1465.60	0.90
13	FEB.14/87	8:00 am	-10	NO APPLICATIONS		
	TOTAL			0.00	0.00	0.00
14	FEB.16/87	4:35 am	-19	960.00	757.60	
	TOTAL			960.00	757.60	0.79

TABLE A2 (continued)

STORM NO.	DATE	TIME	TEMP ^{o}C	SALT SAND kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO (2) CMA MIX :SALT MIX
15	MAR.30/87	11:25 pm	0		178.30	
	MAR.31/87	11:55 am	-5	1136.40		
	APR.1/87	1:45 am	-6	1136.40		
		6:10 am	-6		713.00	
		7:55 am	-1	1136.40		
	TOTAL			3409.20	891.30	0.26

(2) CMA MIX:SALT RATIO FORMULA

$$\frac{\text{(kg of CMA SAND MIX applied per 2-lane km)}}{\text{(kg of SALT SAND MIX applied per 2-lane km)}}$$

EXAMPLE STORM 1

$$\frac{(2688)}{(4364)} = 0.62$$

APPENDIX B

APPLICATIONS OF DEICERS DURING THE WINTER OF 1987-8

TABLE B1: APPLICATION OF CHEMICALS TO QEW

STORM NO.	DATE	TIME	TEMP °C	SALT kg per 2-lane km	SALT SAND kg per 2-lane km	CMA kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO CMA:SAND
1	DEC. 4/87	5:45 am	-2	128.6		171.9		
	TOTAL			128.6		171.9		1.3
2	DEC. 5/87	1:05 am	0	128.6		171.9		
		2:30 am	0				1253.9	
	TOTAL			128.6		171.9	1253.9	2.7
3	DEC.15/87	7:20 am	-1	148.6		111.4		
		10:15 pm	-3	148.6		180.8		
	TOTAL			297.2		292.2		1.0
4	DEC.28/87	9:30 pm	-3	260.0		177.6		
		10:15 pm	-3				749.0	
		11:50 pm	-3		595.0			
	DEC.29/87	2:15 am	-4		600.0		749.0	
		3:20 am	-4				749.0	
		7:50 am	-6				749.0	
		8:45 am	-6		600.0		749.0	
		10:50 am	-7	333.3		178.9		
		1:25 pm	-8	108.3		180.8		
	TOTAL			701.6	1795.0	537.3	3745.0	1.1
5	JAN. 4/88	5:00 am	-3		595.0		721.9	
		6:20 am	-3	194.3		111.4		
	TOTAL			194.3	595.0	111.4	721.9	0.7
6	JAN.14/88	4:55 am	-11		600.0			
		6:20 am	-11				721.9	
	TOTAL				600.0		721.9	1.1
7	JAN.21/88	6:25 am	-1	148.6		177.6		
	TOTAL			148.6	0.0	177.6	0.0	1.2
8	JAN.23/88	5:40 am	-2	148.6		180.8		
		8:40 am	-2	185.7		180.8		
		7:35 am	-2	148.6		180.8		
	TOTAL			482.9	0.0	542.4	0.0	1.1

TABLE B1: APPLICATION OF CHEMICALS TO QEW (cont'd)

STORM NO.	DATE	TIME	TEMP °C	SALT kg per 2-lane km	SALT SAND kg per 2-lane km	CMA kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO CMA:SAND
9	JAN.25/88	9:45 pm	-2	271.0		177.6		
		10:40 pm	-2				721.9	
		11:45 pm	-3				749.3	
	JAN.26/88	1:10 am	-3	131.4			721.9	
		2:50 am	-3			194.8		
		5:10 am	-4			177.6		
		6:30 am	-4	131.4				
		10:30 am	-5			173.3		
		1:30 pm	-5			173.3		
		2:55 pm	-5				833.3	
		3:30 pm	-5		595.0			
		4:25 pm	-5				937.5	
		8:40 pm	-7				532.7	
		10:30 pm	-10	131.4				
	TOTAL			665.2	595.0	896.6	4496.6	2.0
10	FEB. 2/88	12:50 am	-2	148.6		178.5		
		2:25 am	-2	222.9				
		4:25 am	-2			180.6		
		5:40 am	-3	222.9				
		6:10 am	-3			180.6		
		7:05 am	-2			180.6		
		2:15 pm	-1		500.0			
		9:40 pm	-1			106.8		
	FEB. 3/88	12:20 am	-2				791.8	
		8:15 pm	-5	222.9		205.2		
		10:10 pm	-7		600.0		791.8	
	FEB. 4/88	12:20 am	-5		595.0			
		4:30 am	-5	222.9		221.0		
		8:35 am	-5		595.0		791.8	
		9:15 am	-5		600.0		791.8	
	TOTAL			1040.2	2890.0	1253.3	3167.2	1.2
11	FEB. 7/88	7:00 pm	-6		600.0		791.8	
		9:10 pm	-6	131.4		205.2		
	FEB. 8/88	1:10 am	-7		600.0			
		2:35 am	-8			205.2		
		5:20 am	-12				791.8	
	TOTAL			131.4	1200.0	410.4	1583.6	2.0

TABLE B1: APPLICATION OF CHEMICALS TO QEW (cont'd)

STORM NO.	DATE	TIME	TEMP °C	SALT kg per 2-lane km	SALT SAND kg per 2-lane km	CMA kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO CMA:SAND
12	FEB. 9/88	5:25 am	-11		600.0		791.8	
		6:30 am	-11	148.6		205.2		
		9:05 am	-8	148.6		205.2		
		10:55 am	-6			206.1		
	TOTAL			297.2	600.0	616.5	791.8	1.9
13	FEB.11/88	2:35 am	-8		600.0		791.8	
		3:50 am	-8		600.0		791.8	
		5:40 am	-8	131.4			791.8	
		9:05 am	-6			221.0		
		4:10 pm	-3	148.6		198.3		
		5:45 pm	-3		595.0	198.3		
	FEB.12/88	12:45 am	-1	131.4		205.2		
		2:35 am	-2	131.4		221.0		
		4:10 am	-1	131.4		221.0		
		6:10 am	-1	131.4		206.1		
		9:15 am	0	185.7		221.0		
		4:10 pm	-3				250.0	
		5:10 pm	-3		38.1			
		8:20 pm	-3				283.3	
	TOTAL			991.3	1833.1	1691.9	2908.7	1.7
14	FEB.13/88	2:00 am	-9		250.0			
		4:30 am	-9		600.0		791.8	
		5:45 am	-9		600.0		791.8	
		9:15 am	-9		500.0			
		9:50 am	-9				192.6	
		1:10 pm	-6				304.1	
		2:00 pm	-6				385.2	
		3:30 pm	-6		283.3			
		7:25 pm	-6		283.3			
	TOTAL			0.0	2516.6	0.0	2465.5	0.9
15	FEB.19/88	5:00 pm	0	148.6				
		6:40 pm	0			198.1		
		9:15 pm	0				791.8	
	TOTAL			148.6	0.0	198.1	791.8	2.1
16	FEB.26/88	11:55 am	-3				791.8	
		12:50 pm	-3		342.9			
	TOTAL			0.0	342.9	0.0	791.8	2.2

TABLE B1: APPLICATION OF CHEMICALS TO QEW (cont'd)

STORM NO.	DATE	TIME	TEMP °C	SALT kg per 2-lane km	SALT SAND kg per 2-lane km	CMA kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO CMA:SAND
17	FEB.27/88	7:35 am	-3		600.0			
		8:00 am	-3				791.8	
		9:00 am	-3	133.3		198.1		
	TOTAL			133.3	600.0	198.1	791.8	1.4
18	FEB.29/88	1:35 am	1	133.3		205.2		
	TOTAL			133.3	0.0	205.2	0.0	1.5
19	MAR.14/88	4:35 am	-2	148.6		178.5		
	TOTAL			148.6	0.0	178.5	0.0	1.2
20	MAR.19/88	7:30 am	-3			198.1		
		8:00 am	-3	114.3				
		9:10 pm	-3				385.2	
		11:10 pm	-3				385.2	
	MAR.20/88	12:01 am	-3			117.8		
		1:30 am	-3	114.3		221.0		
	TOTAL			228.6	0.0	536.9	770.4	2.8

(1) CMA: SALT RATIO FORMULA

$$\frac{\text{(kg of CMA applied per 2-lane km)} + \text{(kg of CMA SAND MIX applied per 2 lane km} \times 0.14)}{\text{(kg of SALT applied per 2-lane km)} + \text{(kg of SALT SAND MIX applied per 2 lane km} \times 0.15)}$$

TABLE B2: APPLICATION OF CHEMICALS TO SERVICE ROADS

STORM NO.	DATE	TIME	TEMP °C	SALT SAND kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO CMA:SAND
1	DEC. 4/87	5:45 am	-2		248.6	
	TOTAL				248.6	-
2	DEC. 5/87	2:30 am	0		721.9	
		5:10 am	0	500.0		
	TOTAL			500.0	721.9	1.4
3	DEC.15/87	7:20 am	-1	500.0		
		10:15 pm	-3		701.4	
	TOTAL			500.0	701.4	1.4
4	DEC.29/87	3:20 am	-4		749.0	
		4:10 am	-4	500.0	701.4	
		3:15 pm	-8	375.0	258.6	
	DEC.30/87	11:20 am	-6	283.0		
	TOTAL			1158.0	1709.0	1.5
5	JAN. 4/88	5:00 am	-3	595.0		
		6:20 am	-3		721.9	
	TOTAL			595.0	721.9	1.2
6	JAN.14/88	4:55 am	-11	783.0		
		6:20 am	-11		721.9	
	TOTAL			783.0	721.9	0.9
7	JAN.21/88			--	--	
	TOTAL			--	--	--
8	JAN.23/88	9:40 am	-2		398.8	
		12:35 pm	-2	500.0	924.6	
		8:10 pm	-3		398.8	
		11:00 pm	-3	283.3		
	TOTAL			783.3	1722.2	2.2

TABLE B2: APPLICATION OF CHEMICALS TO SERVICE ROADS (cont'd)

STORM NO.	DATE	TIME	TEMP °C	SALT SAND kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO CMA:SAND
9	JAN.25/88	10:40 pm	-2		721.9	
	JAN.26/88	4:00 am	-4	500.0	721.9	
		1:30 pm	-5	495.8		
		8:00 pm	-7	500.0		
	TOTAL			1495.8	1443.8	1.0
10	FEB. 2/88	3:05 am	-2		644.4	
		8:30 am	-2	500.0		
		3:10 pm	-1		791.8	
		8:30 pm	-1	500.0	791.8	
	FEB. 4/88	2:30 am	-5	495.8	791.8	
		12:10 pm	-5	400.0	791.8	
		9:35 pm	-5	500.0		
	TOTAL			2395.8	3811.6	1.6
11	FEB. 8/88	12:01 am	-7	600.0		
		6:20 am	-12		791.8	
	TOTAL			600.0	791.8	1.3
12	FEB. 9/88			--	--	
13	FEB.11/88	8:50 am	-6	500.0		
		9:30 am	-6		791.8	
		10:30 pm	-3	495.8	791.8	
	FEB.12/88	5:10 pm	-1		558.9	
		8:30 pm	-1	283.3		
	TOTAL			1279.1	2142.5	1.7
14	FEB.13/88	8:30 am	-9		791.8	
		9:15 am	-9	500.0		
		1:10 pm	-6		721.6	
	TOTAL			500.0	1513.4	3.0
15	FEB.19/88	9:15 pm	0	--	791.8	
	TOTAL			0.0	791.8	--

TABLE B2: APPLICATION OF CHEMICALS TO SERVICE ROADS (cont'd)

STORM NO.	DATE	TIME	TEMP °C	SALT SAND kg per 2-lane km	CMA SAND kg per 2-lane km	RATIO CMA:SAND
16	FEB.26/88			--	--	
17	FEB.27/88	9:00 am	-3	41.7	--	
	TOTAL			41.7	0.0	0.0
18	FEB.29/88	1:35 am	1	--	--	
	TOTAL			0.0	0.0	--
19	MAR.14/88			--	--	
	TOTAL			0.0	0.0	0.0
20	MAR.19/88	10:10 pm	-3		558.9	
	MAR.20/88	5:15 am	-3	500.0		
		4:45 am	-3		791.8	
	TOTAL			500.0	1350.7	2.7

(2) CMA MIX:SALT MIX RATIO FORMULA

$$\frac{\text{(kg of CMA SAND MIX applied per 2-lane km)}}{\text{(kg of SALT SAND MIX applied per 2-lane km)}}$$

TABLE B3: APPLICATION OF CHEMICALS TO OPTIMUM TEST AREAS

STORM NO.	DATE	TIME	TEMP	TEST AREA #1		TEST AREA #2		TEST AREA #3		TEST AREA #4	
				CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km
			°C								
1	DEC. 4/87	5:45 am	-2	130.0		160.0		190.0		220	
	TOTAL			130.0	0.0	160.0	0.0	190.0	0.0	220.0	0.0
2	DEC. 5/87	1:05 am	0	130.0		160.0		190.0		220	
		3:35 am	0	130.0		160.0		190.0		220	
	TOTAL			260.0	0.0	320.0	0.0	380.0	0.0	440.0	0.0
3	DEC.15/87	10:05 am	-1	130.0		160.0		190.0		220	
		11:00 pm			570.0		700.0		830		960
	TOTAL			130.0	570.0	160.0	700.0	190.0	830.0	220.0	960.0
4	DEC.28/87	9:30 pm	-3	130.0		160.0		190.0		220	
	DEC.29/87	10:50 am	-7	130.0		160.0		190.0		220	
	TOTAL			260.0	0.0	320.0	0.0	380.0	0.0	440.0	0.0
5	JAN. 4/88	5:00 am	-3	130.0		160.0		190.0		220	
		2:30 pm	-3	130.0		160.0		190.0		220	
	TOTAL			260.0	0.0	320.0	0.0	380.0	0.0	440.0	0.0
6	JAN.14/88	4:55 am	-11	130.0		160.0		190.0		220	
	TOTAL			130.0	0.0	160.0	0.0	190.0	0.0	220.0	0.0
7	JAN.21/88	6:20 am	-11	130.0		160.0		190.0		220	
	TOTAL			130.0	0.0	160.0	0.0	190.0	0.0	220.0	0.0

TABLE B3: APPLICATION OF CHEMICALS TO OPTIMUM TEST AREAS (cont'd)

STORM NO.	DATE	TIME	TEMP	TEST AREA #1		TEST AREA #2		TEST AREA #3		TEST AREA #4	
				CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km
			°C								
8	JAN.23/88	5:40 am	2	130.0		160.0		190.0		220	
		7:35 am	-2	130.0		160.0		190.0		220	
		8:10 pm	2	130.0		160.0		190.0		220	
	TOTAL			390.0	0.0	480.0	0.0	570.0	0.0	660.0	0.0
9	JAN.25/88	9:45 pm	2	130.0		160.0		190.0		220	
		11:45 pm	3		570.0		700.0		830		960
	JAN.26/88	1:10 am	3		570.0		700.0		830		960
		5:10 am	-4	130.0		160.0		190.0		220	
		4:25 pm	5		570.0		700.0		830		960
		8:40 pm	-7		570.0		700.0		830		960
	TOTAL			260.0	2280.0	320.0	2800.0	380.0	3320.0	440.0	3840.0
10	FEB. 2/88	12:50 am	-2	130.0		160.0		190.0		220	
		3:05 am	2		570.0		700.0		830		960
		2:15 pm	-1	130.0		160.0		190.0		220	
		8:40 pm	1		570.0		700.0		830		960
	FEB. 3/88	8:15 pm	-5	130.0		160.0		190.0		220	
	FEB. 4/88	2:00 am	5		570.0		700.0		830		960
		8:35 am	-5	130.0		160.0		190.0		220	
	TOTAL			520.0	1710.0	640.0	2100.0	760.0	2490.0	880.0	2880.0
11	FEB. 7/88	7:00 pm	-6		570.0		700.0		830		960
	FEB. 8/88	4:10 am	7	130.0		160.0		190.0		220	
	TOTAL			130.0	570.0	160.0	700.0	190.0	830.0	220.0	960.0
	FEB. 9/88	10:55 am	-6	130.0		160.0		190.0		220	
	TOTAL			130.0	0.0	160.0	0.0	190.0	0.0	220.0	0.0

TABLE B3: APPLICATION OF CHEMICALS TO OPTIMUM TEST AREAS (cont'd)

STORM NO.	DATE	TIME	TEMP	TEST AREA #1		TEST AREA #2		TEST AREA #3		TEST AREA #4	
				CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km
			°C								
13	FEB.11/88	2:35 am	-8		570.0		700.0		830		960
		10:40 am	6	130.0		160.0		190.0		220	
		9:40 pm	-6	130.0		160.0		190.0		220	
	FEB.12/88	6:10 am	-1	130.0		160.0		190.0		220	
		4:10 pm	3	130.0		160.0		190.0		220	
		5:10 pm	-3	130.0		160.0		190.0		220	
	TOTAL			650.0	570.0	800.0	700.0	950.0	830.0	1100.0	960.0
14	FEB.13/88	5:45 am	9		570.0		700.0		830		960
		3:30 pm	-6		570.0		700.0		830		960
	TOTAL			0.0	1140.0	0.0	1400.0	0.0	1660.0	0.0	1920.0
	FEB.19/88	6:40 pm	0	130.0		160.0		190.0		220	
	TOTAL			130.0	0.0	160.0	0.0	190.0	0.0	220.0	0.0
16	FEB.26/88	11:55 am	-3		570.0		700.0		830		960
	TOTAL			0.0	570.0	0.0	700.0	0.0	830.0	0.0	960.0
17	FEB.27/88	9:00 am	-3	130.0		160.0		190.0		220	
		10:20 am	-3		570.0		700.0		830		960
	TOTAL			130.0	570.0	160.0	700.0	190.0	830.0	220.0	960.0
18	FEB.29/88	1:35 am	-1	130.0		160.0		190.0		220	
	TOTAL			130.0	0.0	160.0	0.0	190.0	0.0	220.0	0.0

TABLE B3: APPLICATION OF CHEMICALS TO OPTIMUM TEST AREAS (cont'd)

STORM NO.	DATE	TIME	TEMP	TEST AREA #1		TEST AREA #2		TEST AREA #3		TEST AREA #4	
				CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km	CMA kg per 2-lane km	MIX kg per 2-lane km
			°C								
19	MAR.14/88	4:35 am	-2	130.0		160.0		190.0		220	
	TOTAL			130.0	0.0	160.0	0.0	190.0	0.0	220.0	0.0
20	MAR.19/88	7:30 am	-3	130.0		160.0		190.0		220	
		9:55 pm	-3		570.0		700.0		830		960
	MAR.20/88	5:45 am	-3		570.0		700.0		830		960
	TOTAL			130.0	1140.0	160.0	1400.0	190.0	1660.0	220.0	1920.0